HYDRO - ELECTRICAL DEVELOPMENT
ON THE
COLUMBIA RIVER AT THE DALLES, OREGON

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

1914

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PROPOSED HYDRO-ELECTRICAL DEVELOPMENT

On The

COLUMBIA RIVER AT THE DALLES, OREGON.

A THESIS

Presented by

Walter M. Ehrlich

W. F. Roberts

Joseph C. Norton

To The

PRESIDENT AND FACULTY

Of

ARMOUR INSTITUTE OF TECHNOLOGY

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BACHELOR OF SCIENCE IN CIVIL ENGINEERING

Having Completed The Prescribed

Course Of Study In

CIVIL ENGINEERING

1914.

Approved

Alfred E Phillips

Prof. of Civil Engineering

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Preface.

Owing to tne enormity of tne project, it
has been impossible to go into the details of
the design. The thesis may be considered more
or less as a preliminary design from which
more accurate plans and details may be evolved.

Only standard machinery and standard aux-
iliary apparatus have been used, no original
designes being attempted. The Keokuk water plant
which has been in successful operation for pra-
ctically a year is probably the only other hydro-
electric station of such large capacity, and it
has been deemed advisable to use it as a refer-
ence.

Table of Contents.

Location.

The proposed power site is located on the
Columbia River about ninety miles from the City
of Portland, and one hundred and eighty seven
miles above the mouth of the river. The Columbia
River is now navigable with ease, for deep draft
ocean vessels to the mouth of the Willamette
River, ninety miles above the mouth, and for
the remaining eighty nine miles, is navigable
at all times except in extreme high water stages,
for vessels of eighty foot draft, the power site
being at the present head of navagation.

The proposed scheme is to divert the water
by means of a canal on the Washington side of
the river at a point which is known as Five
Mile Rapids, about five miles above the City of
The Dalles, Oregon. The river at this point sud-
denly contracts from a width of low water of a-
bout sixteen hundred feet to a width of about
two hundred feet, and remains nearly this nar-
row throughout the length of Five Mile Rapids

Annual Discharge Curve
of
The Columbia River
at
The Dalles Oregon.

Fig. 1.

Discharge — in cubic feet per second

700000
600000
500000
400000
300000
200000
100000
0

July. Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. April. May. June.

or to Big Eddy, about one and one half miles below. The proposed location of the power house is at the above mentioned "Big Eddy".

The Columbia River is one of the largest **streams** in the United States. Above the power site under consideration, it drains an area of approximately two hundred and fifty thousand square miles, much. of which is mountainous.Many of its tributaries are fed by melting snow and glaciers in the high altitudes, to which is attributed its most prominent characteristics of flow, namely; the regularity of the occurrence of its annual flood in June when the rainfall on its drainage area is very small, and its general steadiness of flow, free from the sudden and unexpected floods,and droughts so common. to Middle West streams at almost any season of the year. Records of the flow of the Columbia River are available for the past thirty three years.

Curve sheet No.1 shows the average hydrograph for years 1901 - 1912 (1911 omitted).

Annual Average Duration of Flood Curve
for
The Columbia River
at
The Dalles Oregon.

Fig 2

Cubic feet per second.

Days per year.
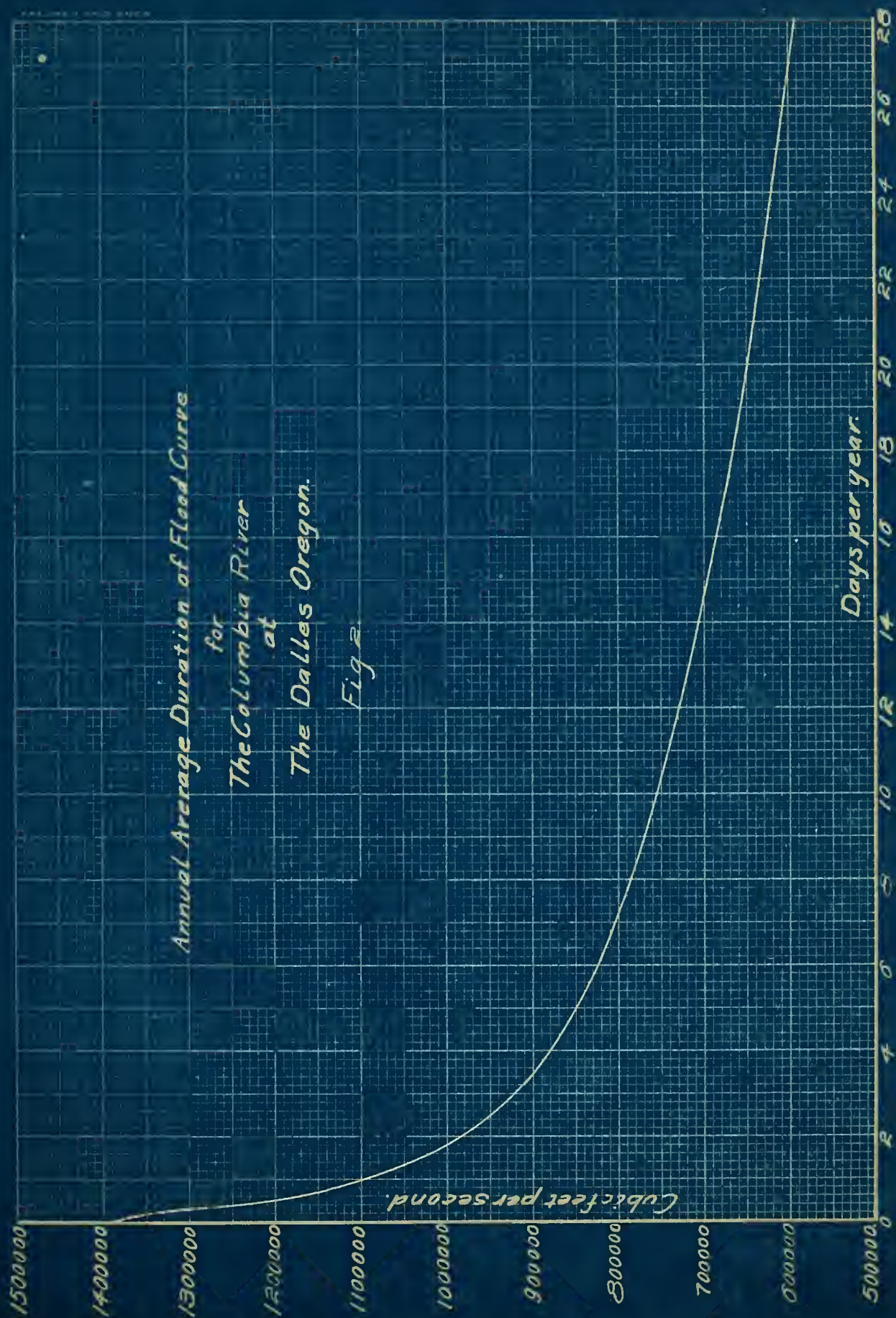
What may be called the " normal flow period"
of the river, will be seen to extend from
September to about March. Two periods are
particularly important in the study of a stream
for power purposes - the flood period and the
low water period.

By reference to Curve Sheet No.1, it will
be seen that June is the normal flood month and
an examination of the records has indicated that
the time of occurrence is very regular. From
diagrams, it has been found that the maximum
flood on record occured in 1894, and a magni-
tude of 1390000 cubic feet per second. Curve
sheet No. 2, shows the annual average duration
of floods of various magnitudes in days per
year. Each point on the curve was obtained by
dividing by thirty two the total number of days
during thirty two years in which a given flood
had been exceeded.

Flow of River.

As will be seen from Curve No.1, low water

Duration Curve of Low Flow Period
for
The Columbia River
at
The Dalles Oregon.

Fig 3.

Days per year.

Cu ft. per sec.

120 x10³
100 x10³
80 x10³
60 x10³
40 x10³
20 x10³
0
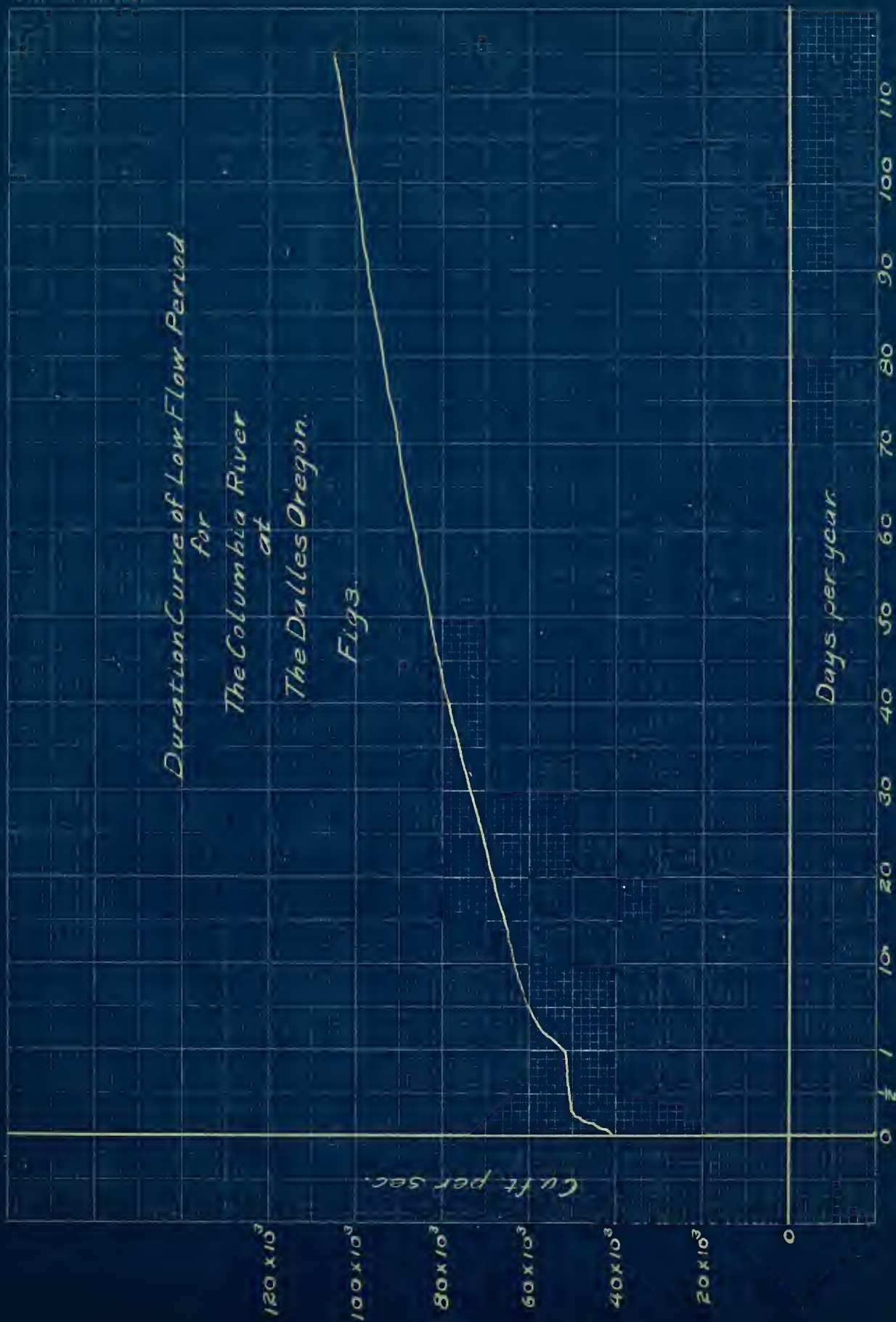
in the Columbia River occures during the winter time when the smaller tributaries are largely ice bound, and the extreme minimum flow probably occures during the few days when the river and its tributaries are freezing, the freezing process acting in a two-fold manner to reduce the stream flow, namely; by drawing a large amount of water from the stream and converting it into ice, and second, by so increasing the resistance of the river to the passage of water as to cause the general water level throughout the length of the stream and its tributaries to rise somewhat, thus deducting from the flow the volume of water necessary to increase the level.

The extreme minimum flow occured in the winter of 1912, the flow dropping to a value of 40000 cubic feet per second. Curve sheet No.3, shows the duration curve of minimum flows similiar in all respects to Curve No.2. The conclusion to be drawn from the foregoing is that it is very improbable that the flow will fall below 50000 second feet.

NET OPERATING HEAD

CURVE SHEET NO. 5

CU. FT. PER SEC.
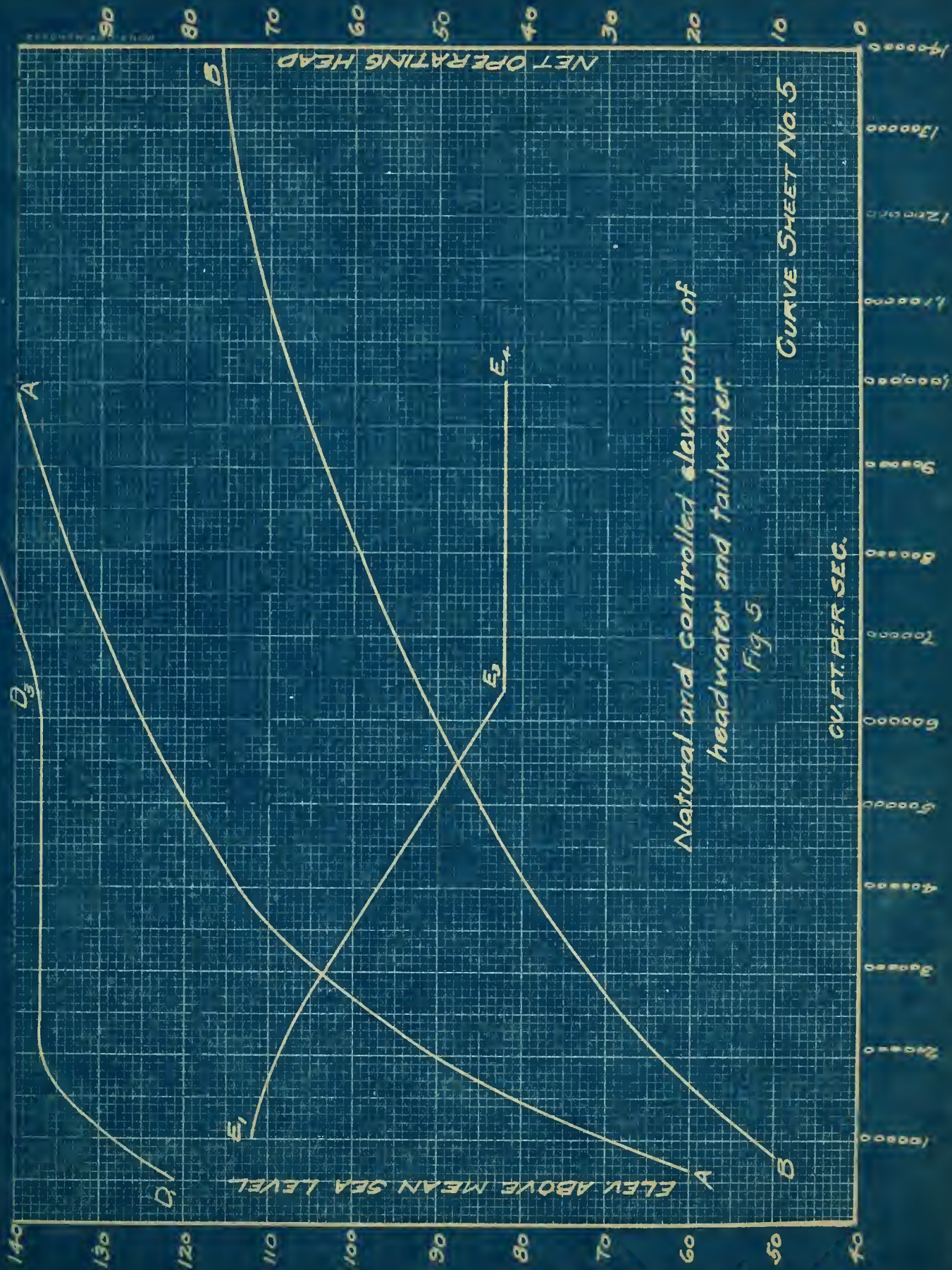
Natural and controlled elevations of
headwater and tailwater.

Fig. 5

ELEV. ABOVE MEAN SEA LEVEL

Available Head.

In Curve sheet No.5, the Curve BB shows the elevation above mean sea level of the water surface in Big Eddy for the entire range of flow of the river, where a total fluctuation in level of about seventy feet will be observed. This elevation will remain essentially unchanged subsequent to the construction of a power plant.

The head water elevation, however, is subject to control by means of a dam. In the same diagram, the curve AA shows the normal elevation of the water at the head of Five Mile Rapids, indicating a total fluctuation of about ninety feet.

The difference in elevation at the dam site and power house site, represented by the vertical distance between curves AA and BB, or the present natural fall at all stages of the river, is shown by curve CCC, the scale being at the right of the diagram.

To maintain a constant operating head at the power station would require an artificial control of the head water elevation by means of

a dam in such a manner as to make the head water curve parallel with the tail water curve BB. However, since this project requires a canal about one and a half miles long, it would be uneconomical to do this. Since the power of the stream is proportional to the product of discharge by head, it is best to utilize a greater head under low water conditions, and thus obtain a greater amount of power, allowing the additional discharge at higher river stages to compensate for the reduced head by the additional machinery.

It is a well established fact that a turbine operating at other than its normal speed or speed of best efficiency, is subject to erosion or pitting of the metal of the turbine buckets proper, the cause of which action is not fully explained. In selecting a maximum head therefore, for this station, it is best to determine what minimum head can be realized, and then to select a maximum or low water head differing from the minimum by an amount such as to

keep the two heads within the practicable limits
of operation of a turbine.

Minimum Head.

The head in hydro-electric power stations
is controlled by the height of the back water.
Running parallel to the river are two railroads,
one on each side. Backwater computations have
shown that by slightly raising the grade of each,
it would be possible to bring the head water
elevation to 151.00. This corresponds to a dis-
charge of 1000000 second feet, the maximum flood
for which the plant has been designed. Under
these conditions, the net operating head which
could be utilized at the power station after
deducting for a loss or fall in the water sur-
face of the canal, would be about forty-two feet.

Maximum Head.

With this assumed minimum head, the maximum
practicable range of satisfactory operation
would limit the maximum head to about seventy
feet with the turbines adjusted to operate at
best efficiency at about sixty feet head. The

The minimum tail water elevation at ordinary
river stages (not extreme minimum) is about
elevation fifty, which with seventy feet head,
and by allowing for a drop in the water sur-
face of the canal, would require a head of water
elevation of about one hundred and twenty five
feet under low water operating conditions. The
curve E ,E ,E ,E , of fig. 5 shows the net oper-
ating head for all conditions of flow.

As stated previously, the maximum flood
has been taken as 1000000 second feet. It is
true that a higher discharge has occured, but
reference to Curve sheet No.3 will show that
a flood of 1300000 second feet has occured only
once in thirty-two years. It is good engineer-
ing as well as almost universal practice, to
ignore extreme and remote conditions and to ex-
cept an interruption of service, should these
conditions ever again occur.

Power.

Low Water Conditions: The power of the stream,
based upon the previous assumptions, namely;

50000 second feet minimum flow and seventy feet maximum simultaneous operating head, would be about 330000 horse power, delivered to the generators. This is based upon 80 % turbine efficiency. The power which could be delivered to the switchboard after allowing for generator losses would be approximately 300000 horse power.

High Water Conditions: As the power of a hydraulic turbine decreases **rapidly with** dropping head, it is necessary at high water, in order to maintain the assumed delivery of 300000 horse power, that additional turbines be installed. Due to the immense size of this proposed power plant, the machinery to be installed would, in order to reduce the total number of generating units to a reasonable figure, need to be very large. As the basis upon which **to** estimate, the cost of installation, a generator of 20000 Kilowatt normal rating, driven by a turbine of 32000 horse power capacity at 70 foot head, will be chosen. Eleven of these units would be required to deliver 300000 horse power at 70 foot

head and with overload capacity of the turbines
in service, at 42 head, twenty such **units** would
be required. This corresponds to high water con-
ditions.

Power House.

As stated before, the power house will be
located on the Washington side and will be of
solid masonry construction. It will be 1200
feet long, 140 feet wide, and 200 feet above
its foundations. All the high tension rooms and
transformers will be isolated by means of steel
doors. Provision will also be made so that in
case of fire, oil can be discharged into the
stream. Tunnels for machinery such as oil com-
pressors and storage will be built in the sub-
structure. Also a standard track will be run
into the side of the building together with a
turntable for use in installing machines.

Turbines.

The normal head on the turbines is 60 feet.
Under this condition, as stated before, 330000
horse power at 80 % efficiency would be deliv-
ered to the generators. Since the Keokuk wheels

are the largest which can be shipped, it is
necessary to limit the turbines to this size
and to choose such a capacity as to compare
favorably with the specific speed of the Keokuk
turbines. Calculations have shown that a 30000
horse power wheel at 80 R.P.M. used in this
installation will be similiar to those of Keokuk,
the only changes necessary being in the mechan-
ical details owing to the increased stresses.
Practice has shown that efficiency of 88 per
cent under normal conditions, are not uncommon
and the computations of this installation will
be based on this efficiency under 60 foot head,
and 75 % gate opening. Since the available power
is expressed by

$$\frac{Q \times H \times eff.}{8.8}$$

we can determine the discharge per wheel as

$$Q = \frac{30000 \times 8.8}{60 \times .88} = 5000 \text{ second feet.}$$

The efficiency of the generator at full load
will be specified at 96 % , and with 30000 horse
power delivered to them by the turbines, a net

electrical output per generator of

(3)   30000 x .746 x .96 = 21500 K.V.A.

will be obtained. In order to develop the entire
energy of the stream, eleven wheels will be in
use at this head.

When the head drops to 42 feet, then, con-
sidering the same gate setting, the discharge
through the turbines will equal

(4) $\dfrac{Q}{5000} = \dfrac{(42)}{(60)}$ or   4200

However, at the low head, the turbines will be
overgated and an increase of 25 % in the dis-
charge will be considered. The efficiency will
also fall off, and as a tentitive basis for cal-
culation, will be assumed to equal 70 %. The
horse power output will then equal

(5) $\dfrac{5000 \times 42}{8.8} \times .70 = 16700$ H.P.

In order that 30000 horse power may still be
supplied, twenty turbines will then be necessary.

At the 70 foot head, the discharge for a
$\frac{3}{4}$ gate opening will equal

(6) $\dfrac{Q}{5000} = \dfrac{(70)}{(60)}$ Q = 5400

At this head it will be necessary to undergate
the turbines and a discharge of 5000 second
feet will be assumed. Then the output of the
turbine, specifying an 80 % efficiency will
equal

(7) $$\frac{5000 \times 70}{8.8} \times .80 = 31800 \text{ H.P.}$$

Eleven turbines will be required to furnish
the 330000 horse power.

Generators.

The generators are of the revolving field
type. Owing to the improvments of 60 cycle ap-
paratus it has been decided to adopt this fre-
quency. The revolving parts will be supported
by a thrust bearing underneath the generator.
Three phase currents at 11000 volts will be
generated.

Excitation.

The required excitation will be about 4000
K.W. and will be provided by motor generator
sets. The motors will be operated by a vertical
water wheel-driven alternator, with direct con-
nected exciters.In order to provide for emmerg-

ency, two 4000 K.W. 1100 volt alterrators will
be installed. Each main generator will be supplied with one motor-generator set. Fourteen
induction and six synchronous motors will be
used. Transformers are connected to the low
tension 11000 volt busses and step down to 2200
thereby enabling motor-generator sets to be operated from the main generator. When the power
factor is low, the synchronous motor can be
over-excited and operated from this low tension
bus for line regulation.A storage battery is
also provided for extreme emergencies. Auto
transformers are used for starting, two taps
being used. K2 oil switches will be used for
all switching, and the oil switches for half
and full taps will be electrically interlocked.
Much emphasis has been laid on the importance
of providing for emergencies in the exciter
layout, for a short delay in such a station is
of extreme importance.

Transformers.

The transformers will be of 10000 K.V.A.

capacity, 3 phase, and will raise the voltage
from 11000 to 110000 volts. It will be so ar-
ranged that any machine can be made to feed any
transformer. The main high and low tension bus-
es are sectionalized with the switches between
them, three transformers feeding into one sect-
ion of high tension bus. The transformers will
be protected on the high tension side by means
of overload relays. Potential and current trans-
formers will be placed on the low tension side
of the system, and also on the outgoing lines.

Canal.

The canal for this project will be about
one and one-half miles long and will be dug out
of solid rock. No coffer dams will be required
at ordinary stages and a large amount of ex-
cavated rock can be wasted along the sides of
the canal to form rock filled walls along the
canal in order to retain the water which would
stand above the natural rock surface and to pro-
tect the S.T. & S Railroad. These rock filled
walls will be paved on the water side with con-

crete.

At the low stage, the canal flow will equal

5000 x 11 = 55000 second feet.

while at high water the canal will carry

5000 x 20 = 100000 second feet.

Since the canal is solid rock, the velocity
of the water thru it can run as high as 10 feet
per second. Beginning at a lev.l of 135.00, the
canal will be excavated for a **depth** of twenty
four feet, with a batter of three inches per foot.
The width of the canal at the bottom will equal
three hundred feet. The low water will probably
not drop much below elevation 130.00 The area
of the canal then equals

305 x 20 = 6100 square feet.

The velocity of a discharge of 55000 second feet
equals

$$\frac{55000}{6100} = 9.0 \text{ feet per second.}$$

For such a canal the coefficient of roughness
is about .025. The wetted perimeter equals

300 + 41.22 = 341.22

and the hydraulic radius equals

$$\frac{6100}{341.22} = 17.90$$

Substituting in the Kutter formula using a
three and one half foot drop we obtain a vel-
ocity which checks very closely with the above
velocity.

When the water rises to elevation 151.00,
then the velocity will equal

$$\frac{100000}{14137.25} = 7.70 \text{ feet per second.}$$

The slope of the fill which rises to elevation
155.00 will be one to one. In this case the wet-
ted perimeter equals 410.2 and the hydraulic
radius 34.4. A drop of 1.25 feet gives a vel-
ocity of 7.83 feet per second which also checks
with the previous calculation.

In order that the velocity thru the racks
be as small as possible, the canal will be ex-
cavated to a depth of elevation 80.00 at the
entrance of the power house and the width will
be increased as much as practicable.

Dam.

The rock at the site of the dam is compos-
ed of hard basalt, usually of columnar structure
and quite seamy. The proposed dam is of the rock

fill type, to be built up throughout of large
blocks of rock or of concrete, weighing twenty
or thirty tons. However it would be impractic-
able to design this type of dam for overflow
and therefore a diversion channel is to be con-
structed large enough to accomidate the entire
flow of the river, for permanent as well as
construction purposes, the rock filled dam pre-
viously mentioned being built well above the
maximum flood level. The diversion channel has
already been described, but at the head is pro-
vided a removable type of dam, the purpose of
which is to regulate the river flow.

This removable dam is similiar to those
built for the emergency dams on the Panama Canal,
except for the substitution of a permanent bridge
instead of two draw spans as on the Panama. The
dam will consist of large concrete piers spaced
one hundred feet center to center with the con-
crete arched sills, and at the top heavily re-
inforced concrete beams or horizontal steel gir-
ders enclosed in concrete, between the piers.

Wicket girders of ordinary plate girder type
arranged in pairs will be hinged by pins to the
horizontal beam between piers and rest in an
inclined position in the concrete sill. By means
of cables running from the lower end of the gir-
ders to the hoisting machine, each pair of gir-
ders is made to revolve on its hinges, the up-
stream end of the girders being raised up or
let down as desired. After the wicket girders
are lowered into place, the gates are allowed
to slide down on the girder until they reach
their proper position. (See drawing.)

The bottom of the concrete sills will be
at elevation 106.00, while the wicket girders
will be at elevation 110.00. The rock between
the removable dam and the river bed will be ex-
cavated, giving a slope of about 23 feet in
1000. Assuming a maximum velocity of 20 feet
per second and considering a maximum discharge
of 1400000 second feet, then the required area
equals

$$A \quad \frac{1400000}{41 \times 20} = 1750 \text{ square feet.}$$

This will require eight - 100 foot sections.

As stated before, the horizontal beam will consist of a steel girder. This girder will consist of a $\frac{1}{2}$" web, with 2 - 6" x 8" angles and 4 - 1" x 13" cover plates. Stiffener angles 4" x 4" x 1" will be spaced every six feet.

The gate will comprise a heavy steel sheeting supported by I-beams 25' - 0" in length. The spacing of these I-beams will vary from two feet at the bottom to seven feet at the top. The sheeting will consist of $\frac{3}{4}$" steel and will be reinforced by strips $\frac{1}{2}$" x 6" placed diagonally on the back.

The inclined wicket girders will consist of two web plates, with four angles placed at the corners and then covered with cover plates, generally known as box girders. Calculations have shown that web plates five feet deep and one inch thick will be needed, considering a 20" spacing between them. Four 8" x '" x 1" angles and eight 20" x 1" cover plates will also be required.

Since the pressure from the water varies from zero to a maximum the depth of this girder will also be changed from five feet at the bottom to two feet at the top.

Transmission.

The transmission lines will consist of first class towers constructed on the private right of way. Duplicate three phase lines and one groung wire will be arranged. Only four transmission lines have been computed. The following table shows the size of wire and power delivered.

Town	K.W.	Wire Size.
Umatilla	30000	No. 0000 B & S
Portland	20000	No. 0000 B & S
Salem	5000	No. 2 B & S
Eugene	5000	No. 4 B & S

Market for Power

One cannot expect that a market for such a tremendous amount of power already exists. However, manufacturing industries already recognize electrical operation of factory machinery as the accepted method. Coincident with

the development of the art of generating elec-
trical energy, there has also been a remark-
able readjustment of old manufacturing process-
es and also a great development of entirely new
industries made possible only by the principle
of the electrolytic bath and electric arc. Why
not center some of these industries around this
huge development?

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GENERATOR & EXCITER FLOOR

UNIT NO.1

UNIT NO.2

MAIN GENERATOR EXCITER

MAIN GENERATOR & MOTOR GEN

110,000 V. TRANS
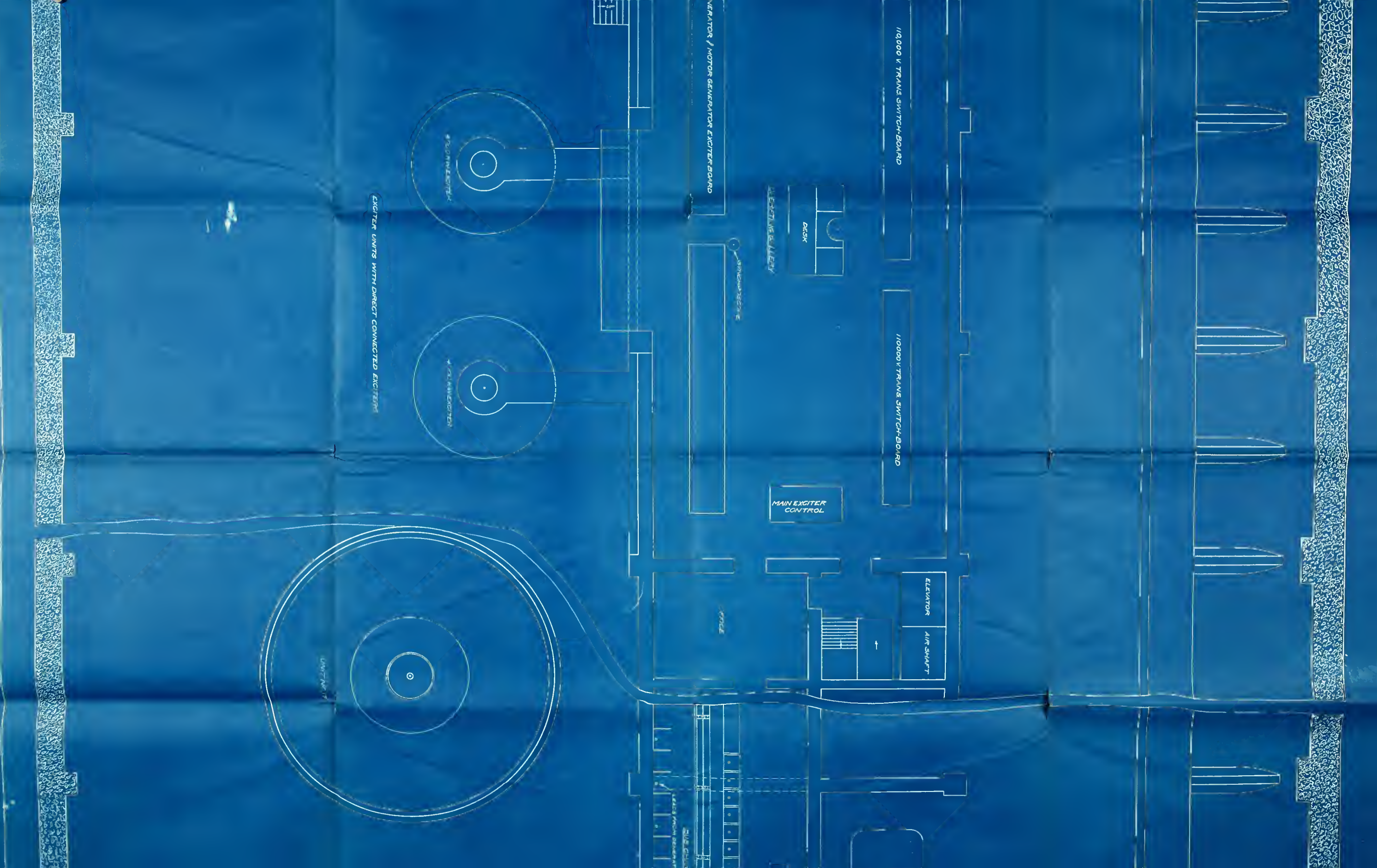
OIL SWITCH FOR TRANS.

OIL SWITCH FOR EXCITER TRANSFORMERS

300 KVA.

300 KVA.

300 KVA.
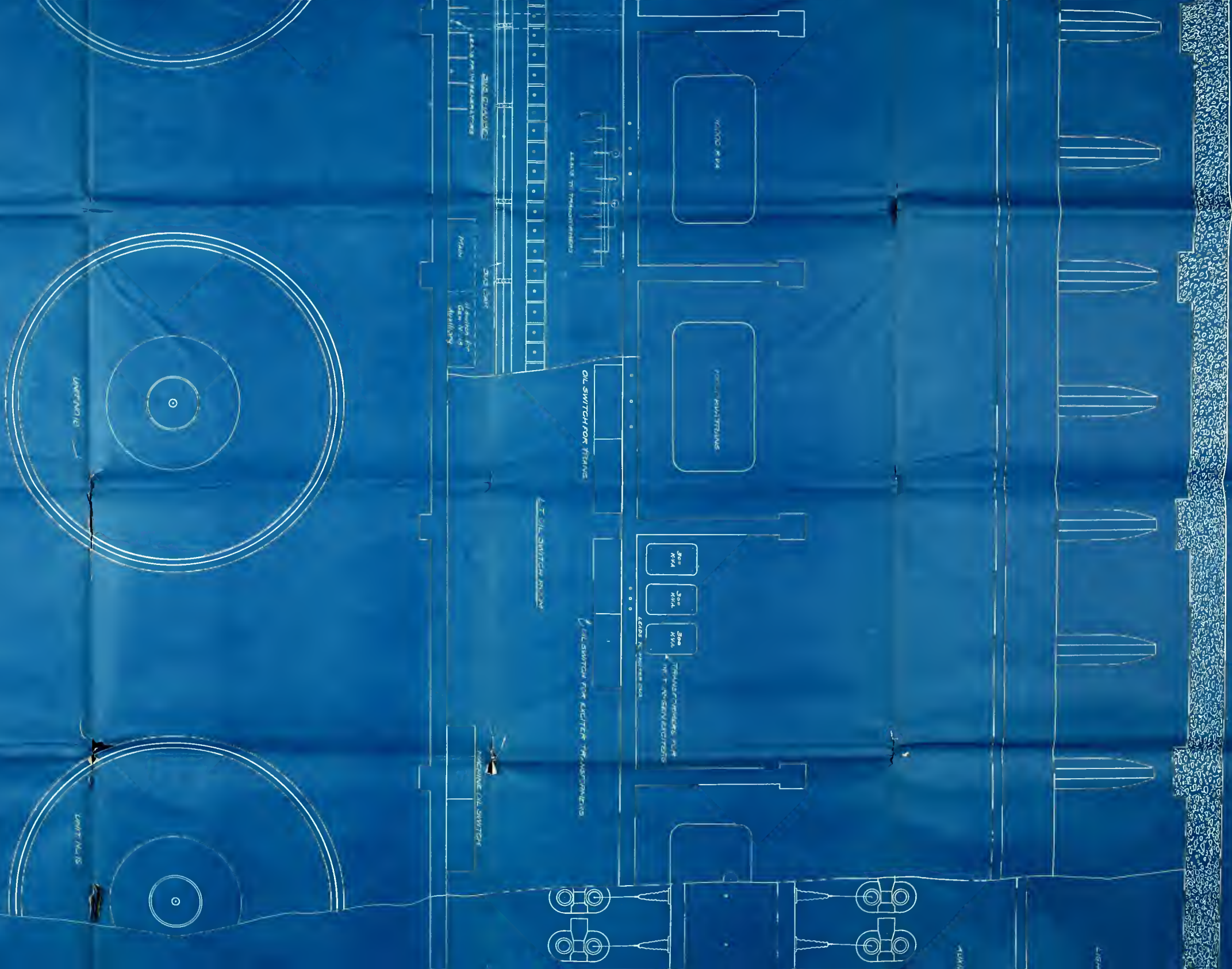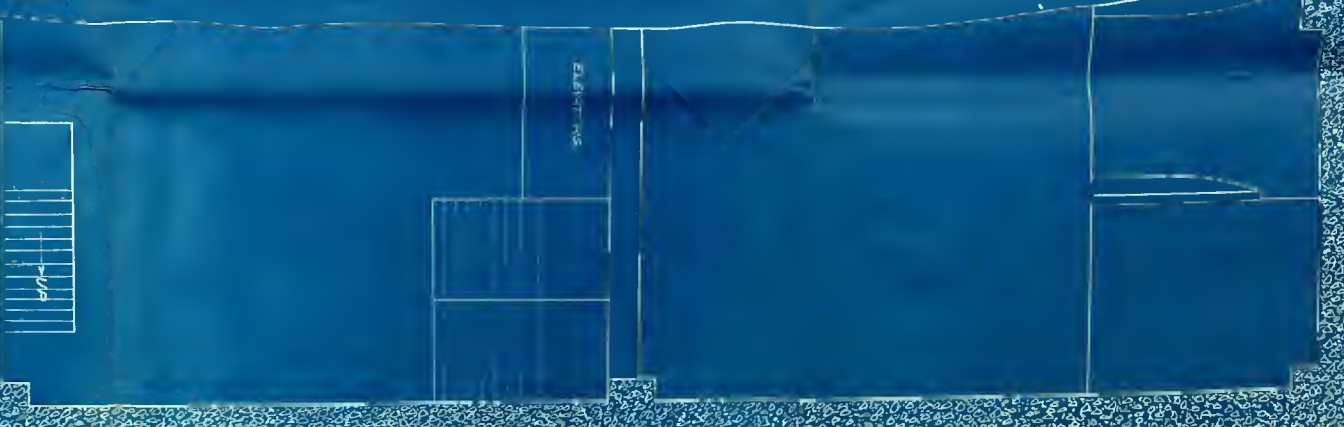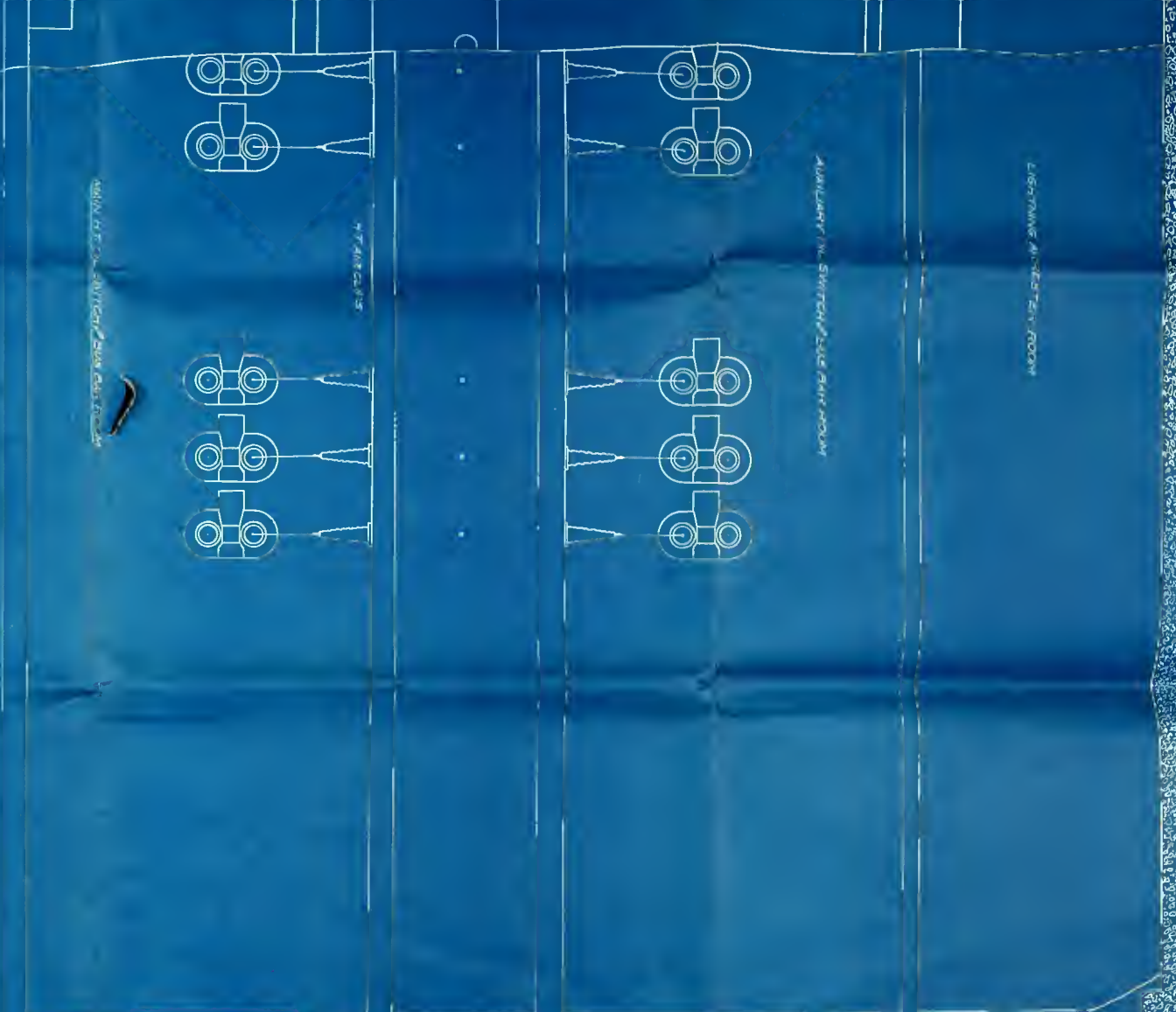
PLAN OF
PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
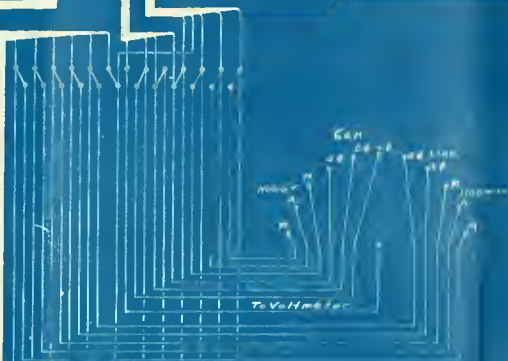COLUMBIA RIVER
THE DALLES
SCALE
MAY 13 1918
DESIGNED BY

CONTROL WIRING DIAGRAM
PROPOSED
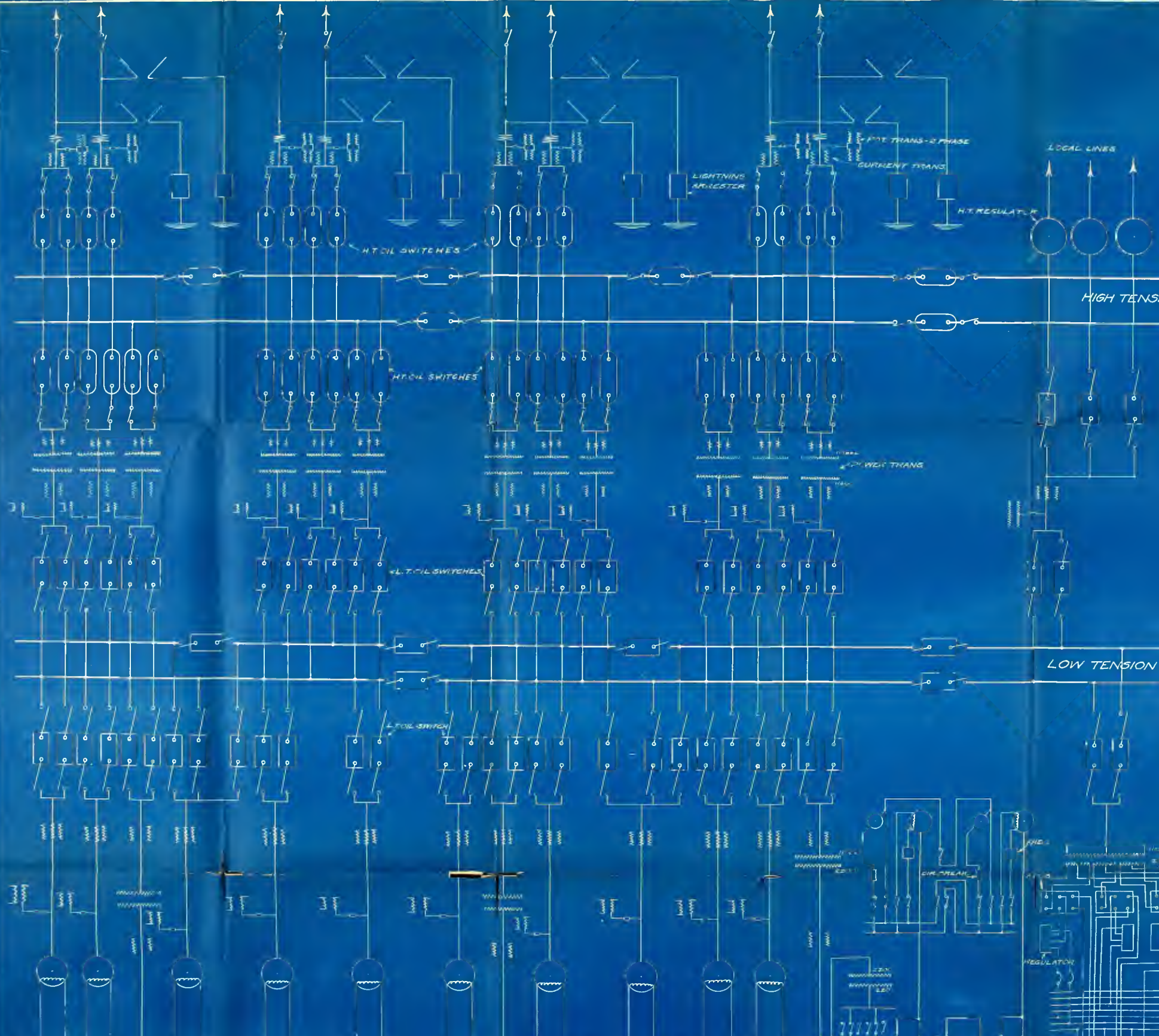
HYDRO-ELECTRIC PLANT

COLUMBIA RIVER
THE DALLES, ORE.
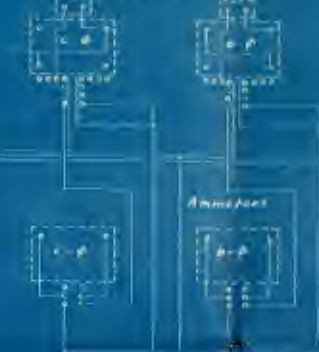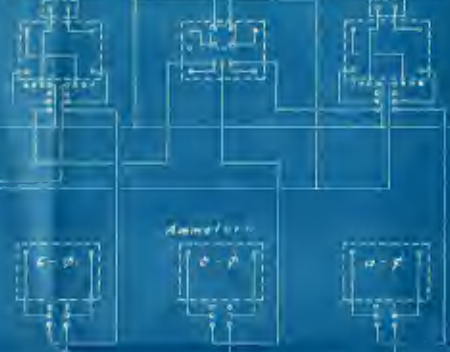
DESIGNED BY

Recording Voltmeters

Main Bus. 11000 V.   Aux. Bus. 11000 V.

Main Bus 11000 V.   Aux. Bus 11000 V.

Int. Wattmeter
Poly-phase

Int. Wattmeter
Poly-phase

Main   Aux.

Main   Aux.

Tie

To Battery.

To Voltmeter.

Gen.

Exciter

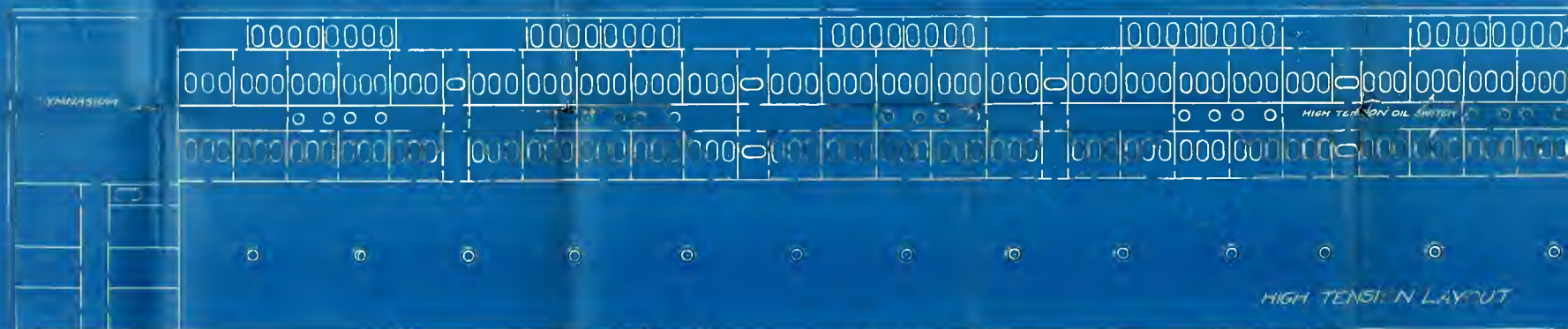| I | Bus & Pot. Potentials | XII | Bus Tie Oil Sw. Control |
II		XIII	Neutral Oil Sw. Control
III	Line Oil Sw. Control	XIV	Syn. Potentials
IV	Line Currents	XV	Line Potentials
V	Trans Oil Sw. Control	XVI	Trans. Currents
VI		XVII	Bus Volt. Potentials
VII	Relay Currents	XVIII	
VIII	Trans Currents	XIX	Line Currents
IX	Gen Potentials	XX	Line Relay Control
X	Syn Potentials	XXI	Gen. Currents
XI	Gen Oil Sw. Control	XXII	Neutral Current

LOCAL LINES

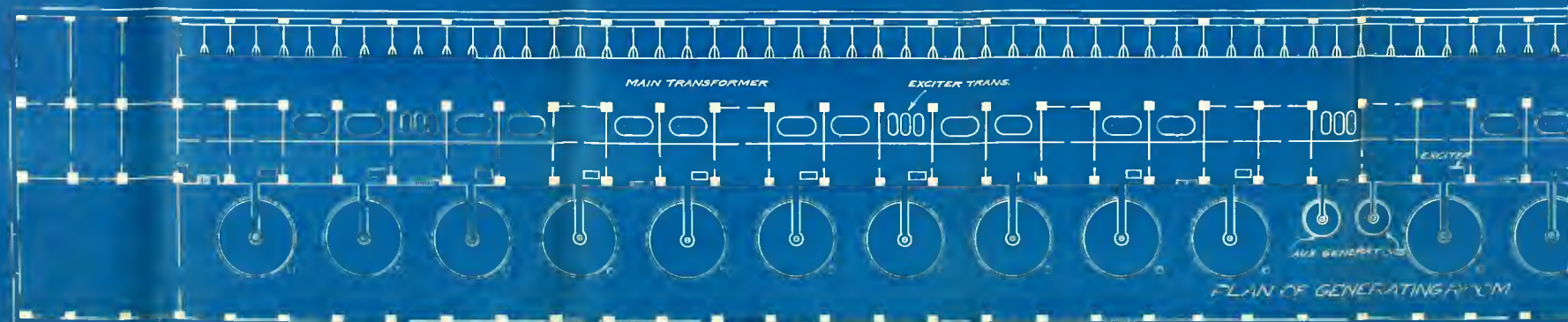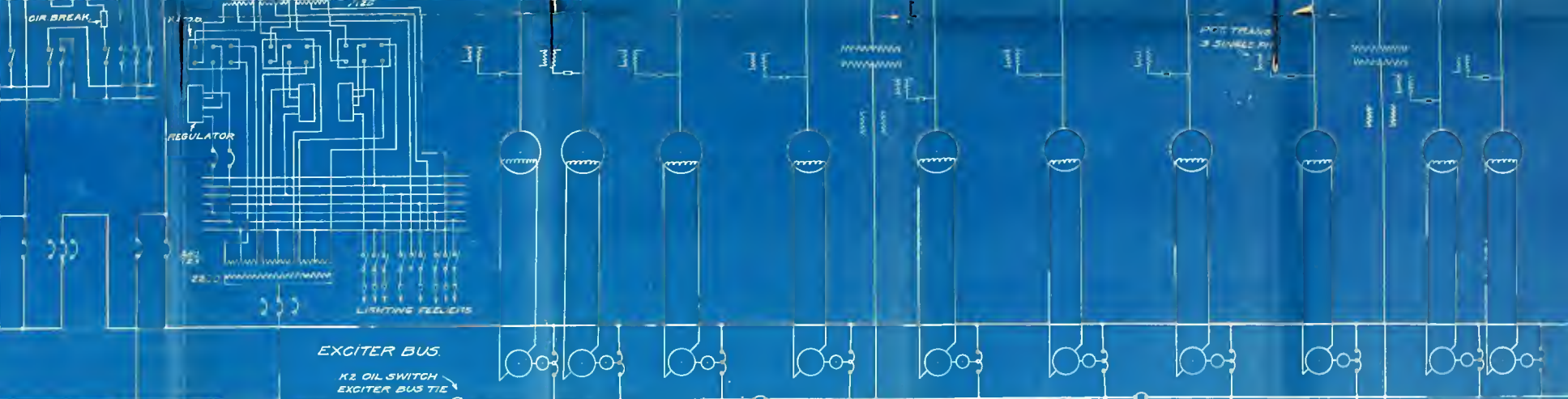POT TRANS-2 PHASE

CURRENT TRANS.

LIGHTNING ARRESTER

H.T. REGULATOR

H.T. OIL SWITCHES

HIGH TENSION

H.T. OIL SWITCHES

WICH TRANS

L.T. OIL SWITCHES

LOW TENSION

L.T. OIL SWITCH

CIR. BREAK.

REGULATOR

HIGH TENSION BUS

LOW TENSION BUS.

REGULATOR

EXCIT

K2 O
EXCIT

POWER TEE 2KV

GYMNASIUM

HIGH TENSION OIL SWITCH

HIGH TENSION LAYOUT

GENERAL PLAN.

MAIN TRANSFORMER   EXCITER TRANS.

EXCITER

AUX GENERATOR

PLAN OF GENERATING ROOM

CIR BREAK.

REGULATOR

LIGHTING FEEDERS

EXCITER BUS.

K2 OIL SWITCH
EXCITER BUS TIE

POT TRANS
3 SINGLE PH

GENERAL WIRING DIAGRAM

PROPOSED

HYDRO-ELECTRIC PLANT

COLUMBIA RIVER
THE DALLES, ORE.

DESIGNED BY

LIGHTNING ARR.

HIGH TENSION OIL SWITCH

H.T. CURRENT TRANS

HIGH TENSION LAYOUT.

GENERAL PLAN.

EXCITER

AUX. GENERATOR

PLAN OF GENERATING ROOM.

IND. WATTMETER

IND. WATTMETER

IND. WATTMETER

0 - 1500

AMMETER

0 - 1500

FREQUENCY IND
45 60 75

POWER FACTOR IND.
.60 1.00 .60

± AMMETER
0 - 400

300
FIELD VOLTMETER

VOLTMETER
0 - 180

0 750
FIELD AMMETER
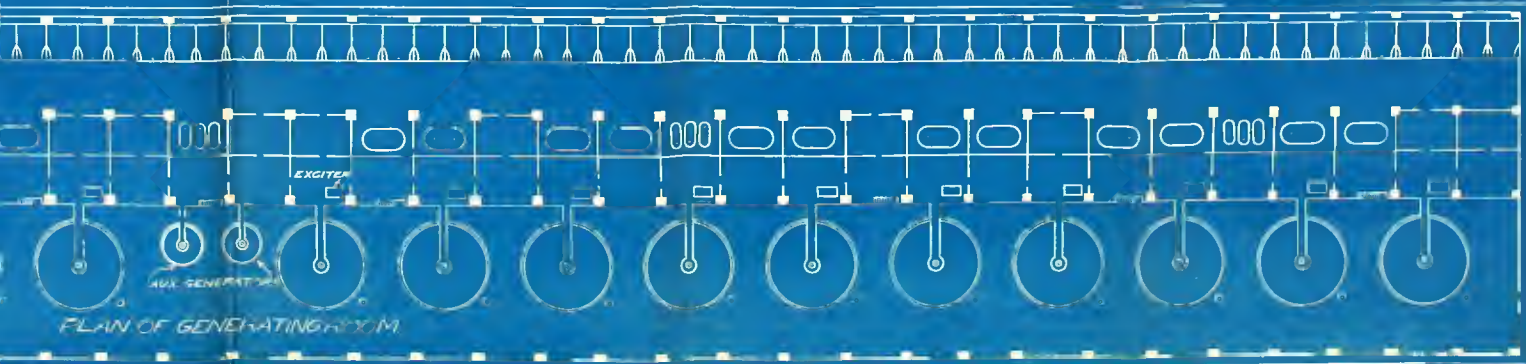
CONTROL BENCH BOARDS

PROPOSED

HYDRO-ELECTRIC PLANT

COLUMBIA RIVER
THE DALLES, ORE.
SCALE ⅜"=1'

DESIGNED BY

GEN'S

EXCITER'S

MIN.

AUX.

MAIN

EX.

TRAN

RUN

START

T.R.

FLD.V

FLD.W

COME

TRAN

GEN.

SECTION

GENERATOR PANEL

SIGNAL LAMPS
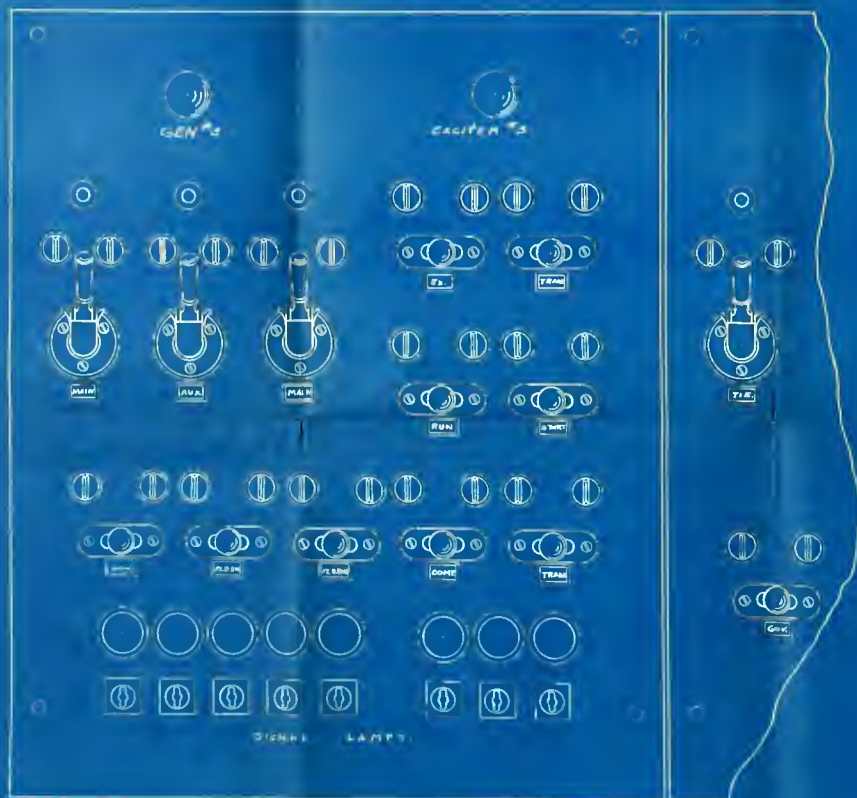
ENCH BOARDS
POSED

CTRIC PLANT

A RIVER
LES, ORE.
$\frac{1}{4}" = 1"$

IND. WATTMETER   P.F. INDICATOR   IND. WATTMETER

0 - 150   AMMETERS.   0 - 150

VOLT METER
0 - 150

MAIN   AUX.   MAIN   AUX.

AMMETER.   IND. WATTMETER

AMMETER   AMMETER

MAIN   AUX

NEL.

AUX.   MAIN   AUX.   MAIN   AUX.   TIE

LINE #1   TRANS. #2   TRANS. #3

MAIN   AUX.

PLAN   PLAN

SECTION

GENERATOR PANEL

PLAN

GENERATOR PANEL

SIGNAL LAMPS

RUN

START

GEN

COMP

TRANS

GEN.
INTEGRATING
WATTMETER

ENGINE
INTEGRATING
WATTMETER

PANEL

AUX. MAIN AUX MAIN AUX. TIE

MAIN AUX.
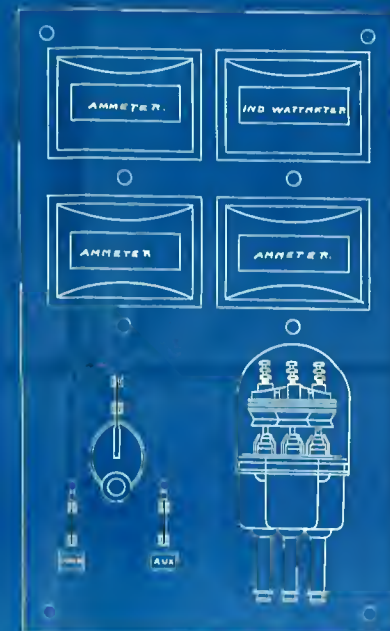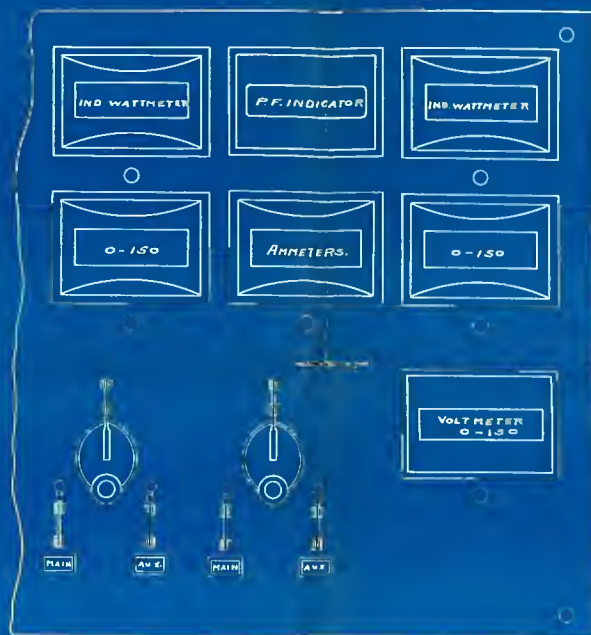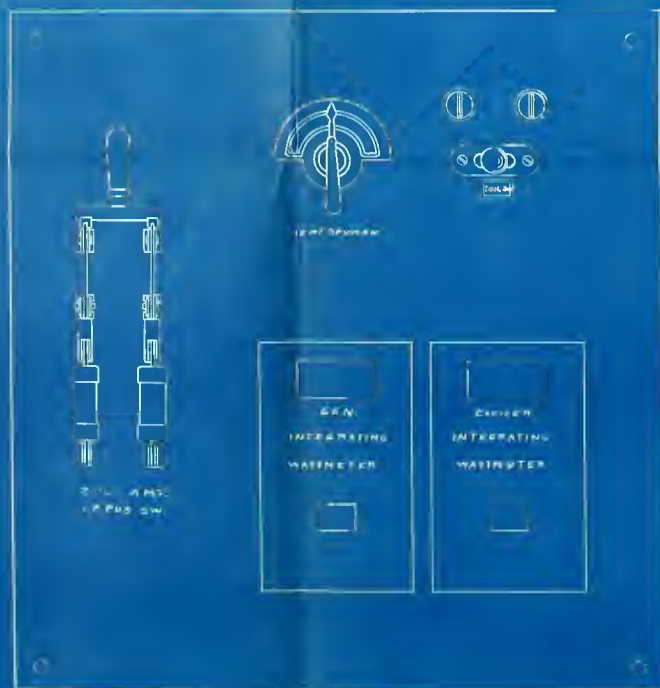
PLAN

HIGH TENSION LINE & TRANS PANEL

PLAN

TRANSFORMER PANEL

RECORDING VOLTMETER

12 PT OSMOSE

INTEGRATING WATTMETER

RECORDING VOLTMETER

REMOVABLE DAM
PROPOSED

HYDRO-ELECTRIC PLANT

COLUMBIA RIVER
THE DALLES, ORE.

DESIGNED BY
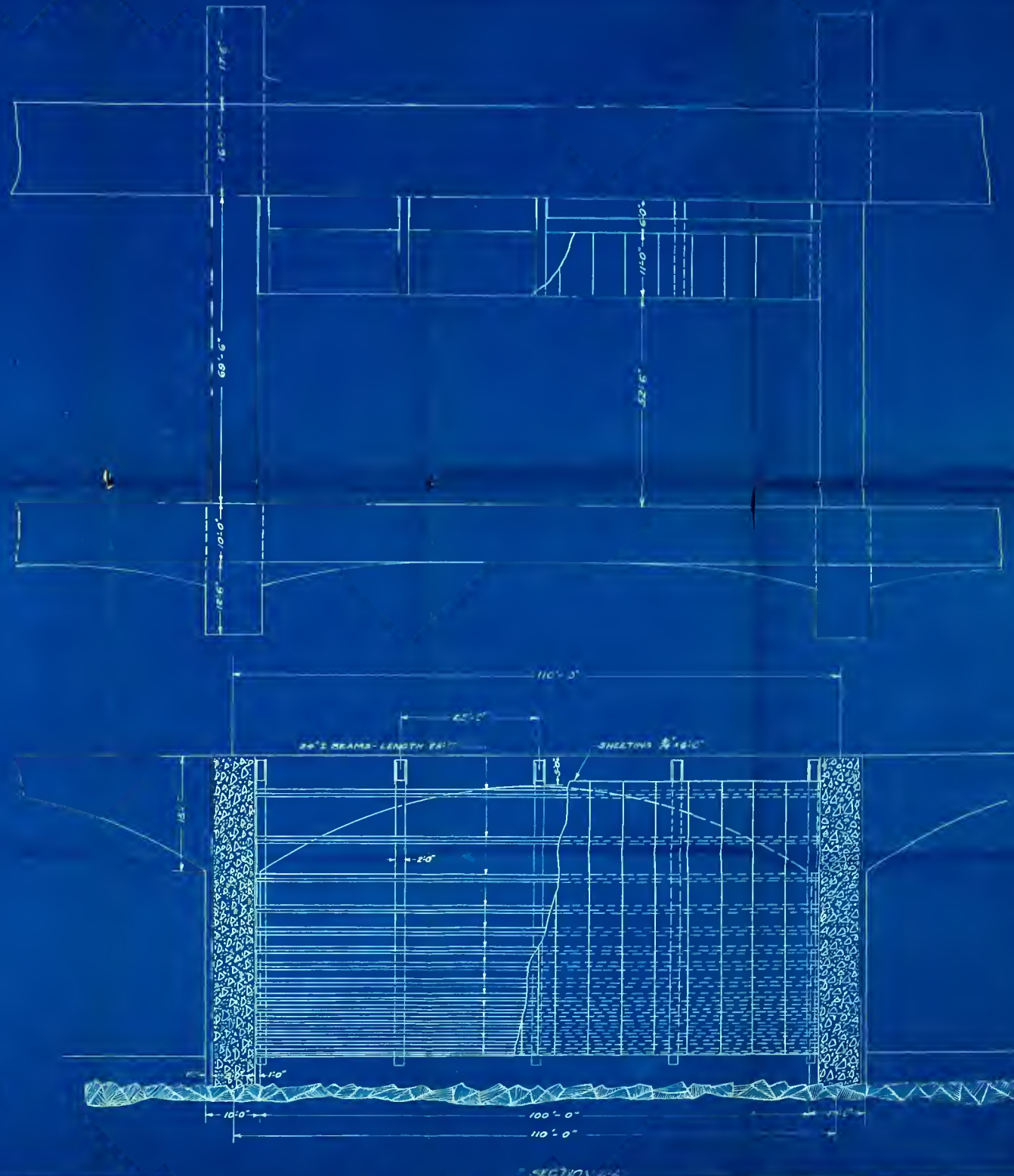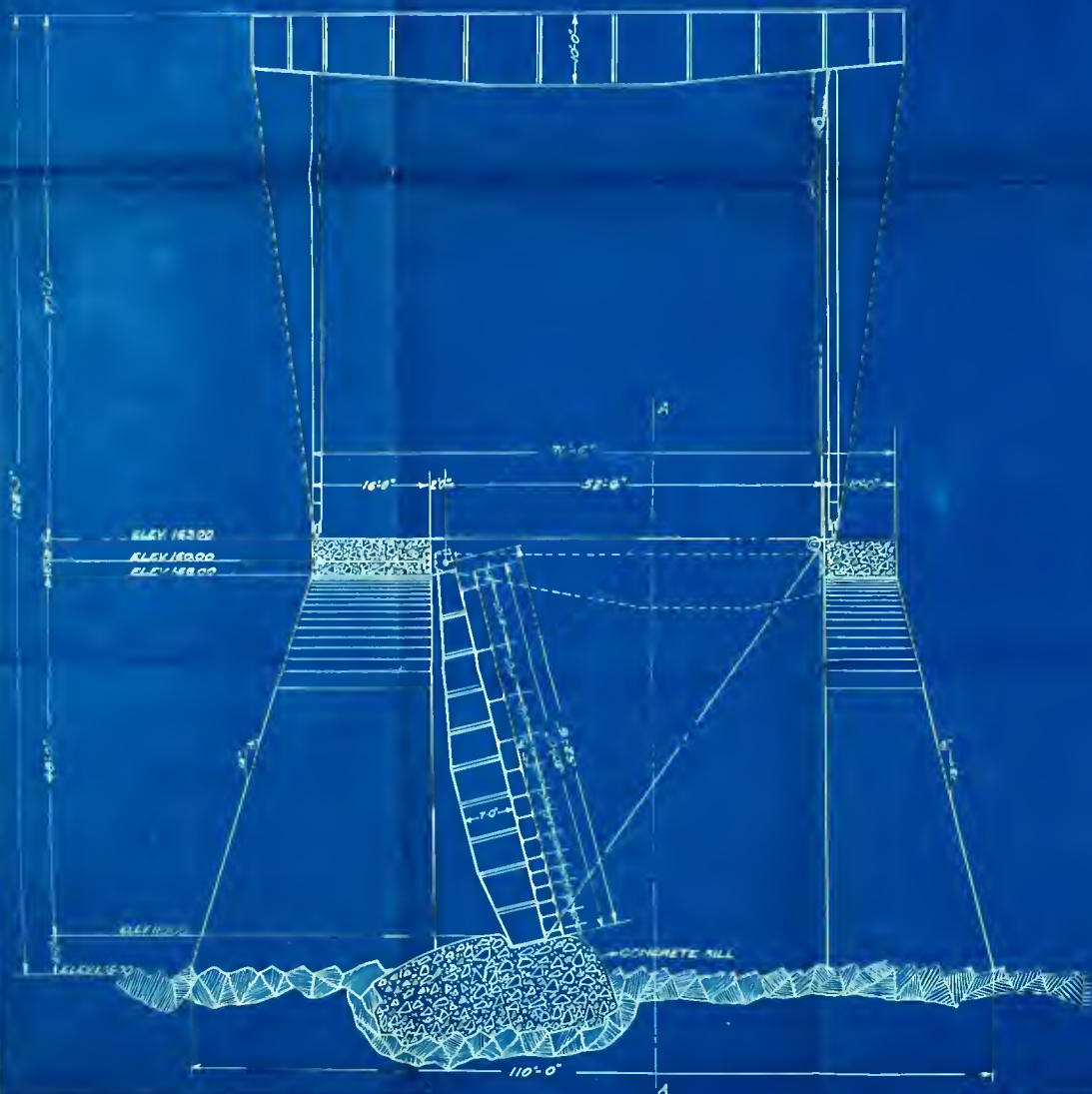
WASHINGTON

POWER CANAL

POWER HOUSE

BIG EDDY

FIVE MILE RAPIDS.

OREGON

O.W.R. and N. CO.

RAPIDS.

N

130

130

110

120

100

90

90

90

130

90

100

110

100

90

100

110

120

100

130

140

130

140

140

150

170

160

ABUT.

ROCK FILL DAM

130

N. CO.

TOPOGRAPHIC MAP
PROPOSED
HYDRO-ELECTRIC PLANT
COLUMBIA RIVER
THE DALLES, ORE.
SCALE 1"=200'

DESIGNED BY